High Power Multilevel Converters – Analysis, Design and Operational Issues
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Lecture - 26
Neutral Point Clamped Converter – Circuit Topology (Part I)

Hello everyone. And today we will start a topic on Neutral Point Clamped Converter. This is one of the multi level converters that is very popular and is extensively used. It was proposed around say the early 1990s, I think around 80 or 81, 81, 82 somewhere around that time; is probably the most popular multi level converter in the market ok, Neutral Point Clamp Converter.

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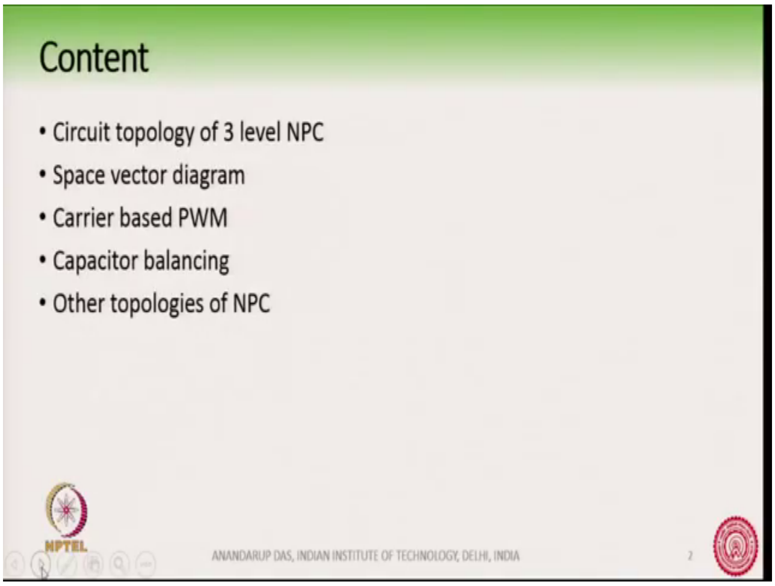

So, what we will cover is the circuit topology of a 3 level Neutral Point Clamp; NPC stands for Neutral Point Clamp Converter. So, we will study circuit topology of 3 level NPC, then space vector diagram and then PWM strategy and capacitor balancing and some other topologies of NPC.

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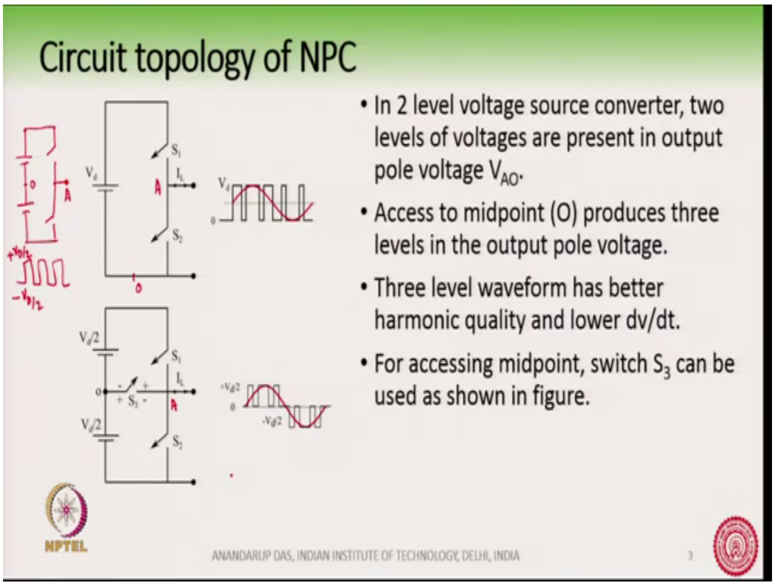

Let us first start with how did we obtain the NPC? So, when this transistor based voltage source converters became popular, people were using the two level VSI or two level voltage source converter. And typically they were using two switches like this here, it is still used. So, it is the most frequently used voltage source converter two switches like this.

Now when it was, when it is being operated it is still valid; the whatever discussions we do is still valid. So, if we run this two level voltage source converter; one drawback, there are several drawbacks which we have earlier said and that is why some people go for a multi level converter in its design. One drawback is that, we need a high switching frequency of the switches, so that the size of the filter is reduced

And if you do not have a filter, then sometimes d v d t on the motor; for example, this converter is driving a motor, then the d v d t on the motor can be quite high, especially with a long cable. So, it was felt that, so a, so if you see here the. If you see here that, the voltage is voltage output of a conventional voltage source two level converter is something like this, where the output voltage is varying between 0 and V d. And by using sin sinusoidal pulse width modulation, we are changing the width of the pulse sinusoidally, so that we get a embedded sin wave inside the output of the converter.

The output waveform here has always an instantaneous error between what the actual voltage which we want to produce and the actual voltage produced by the converter. We have discussed this and so there is always an instantaneous error between the actual voltage produced by the converter and the desired voltage from the converter; the desired voltage from the converter should be this red waveform, ok.

We want a perfect sin wave output from the converter; however, because we have only these two switches S 1 and S 2 in our hand. So, we are only able to produce this voltage waveform which spans between 0 and V d, ok. So, there is always an instantaneous error between what we desire to produce that is the sin wave and what we are actually producing, which is this series of pulses, spanning between 0 and V d

So, the instantaneous error is the source of harmonics in the waveform. So, if we can make a waveform, which is having shape like this here; Where, this is the this red one is the desirable waveform. And what we are actually producing from the converter is like spanning between 0 and V d by 2 here and on the negative side, it is spanning between 0 and minus V d by 2, ok. So, what is the benefit of this? The benefit of this is as compared to this waveform is that; the instantaneous error is less in this waveform,

So, here for example, on the positive side sometimes we were using a pulse which was far away from the red waveform; and here we are using a pulse which is closer to the red waveform as compared to this waveform. So, the instantaneous error is less in this waveform;

that means, if this waveform is more towards a sin wave, we can do the Fourier analysis of this. So, this waveform has is more sinusoidal.

So, the question is how can we get this kind of a waveform from the converter? That can solve many of our problems, which we encounter in a conventional voltage source converter. So, then came the three level converter, ok. This is why it is called three level converter; because there are now three levels of voltages possible from this converter, so V d by 2 0 and minus V d by 2.

Earlier we were having two levels of voltage 0 and V d; now we are having 0 V d by 2 and minus V d by 2, ok. How can I get this is shown in this circuit here, ok. Now, so, the just one second here; so in case of a, so this is was A and this is 0 and this is A and that is 0 here that is O. So, in case of a two level voltage source converter; the V A O voltage can be 0 and V d.

Now, we want to produce three levels of voltage between A and O here, on the diagram here A and O three levels of voltage. So, what do we need therefore, we need three switches; S 1, S 2 and S 3, right. So, for accessing the midpoint of the DC source we are using a third switch, S 3. Now remember that in a two level voltage source converter, the point O we had taken to be the negative of the DC bus.

Some authors take or make a circuit like this also. Some authors denote the voltage source converter as like this. If you put O at the middle of the capacitor, it becomes actually an imaginary point. So, the point O is fictitious or imaginary, it does not exist physically in the circuit. So, for this V, for this circuit here the voltage waveforms will be minus V d by 2 2 plus V d by 2; again two levels plus V d by 2 and minus V d by 2, the 0 level does not exist.

If I take the 0 level to be at the bottom, then I have 0 and V d; as I have shown it in this waveform. In case of a three level inverter; however, this 0 point is actually present in the converter, it is physically accessible and used,. So, this is a physical point inside the converter to which we have connected the switch S 3, ok. So, it is physically present inside the converter.

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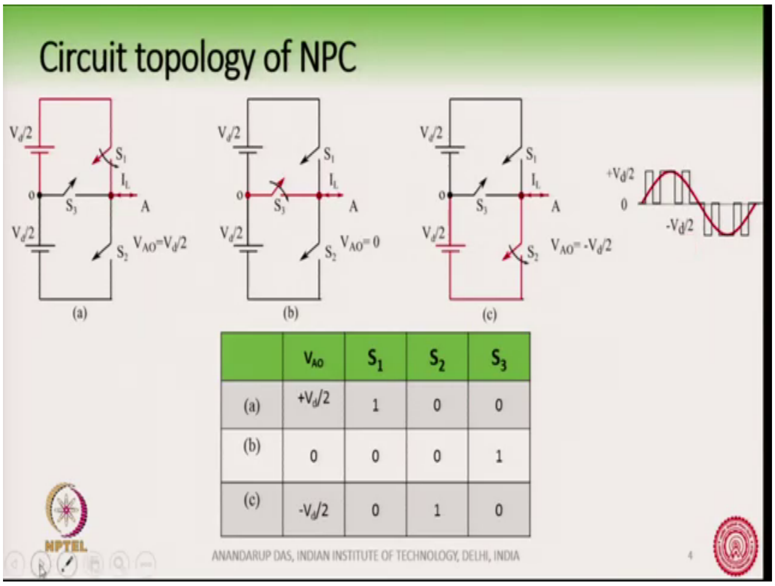

So, let us now see that if I use such a circuit, how can I get three levels of waveform output, ok. So, if I turn on suppose I, this is shown in this figure and also in this table. If I turn on S 1 here and I turn off S 2 and S 3 down on S 1 and I have turned on S turned off S 2 and S 3, I have turned on S 1; then the I get with respect to this O point or 0 point V A O, I will say O point the voltage V A O is V d by 2.

So, this is shown here V A O is V d by 2; when I turn on S 1 and S 2 and S 3 are off. On the other hand, if I look into this c figure; if I turn on S 2 here, this lower switch and I turn off S 1 and S 3, then the voltage V A O will be minus V d by 2, ok. So, this is what is shown here, V AO is minus V d by 2 0, 1, 0; these switches are ideal four quadrant switches, ok. So, they can carry current in both direction and can block the voltage in both direction generic switch here, we have started with that.

Now, if I want to get the midpoint voltage, the O point is often called the midpoint; because it is the midpoint of the two DC sources, usually these two DC sources are made from capacitors. So, if I want to access the midpoint voltage, I will turn on this switch here, and will turn off S 1 and S 2. So, this is what is shown here and in that case if the midpoint voltage is at 0; then I get a 0 voltage at point O

So, therefore, three levels of voltages plus V d by 2 0 and minus V d by 2 are possible at the pole voltage. So, V A O or V A, the A point voltage you can say it is a pole voltage. So, V A O can be 0 V d by 2 or minus V d by 2.

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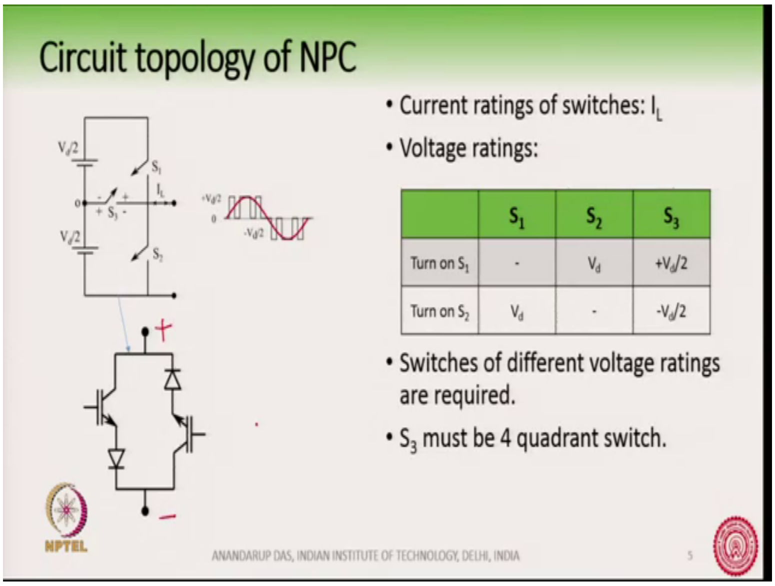

Now, let us see what are the ratings of this switch? What is the what are the ratings of this switch? What is the current rating of these three switches; S 1, S 2 and S 3 ?

The current rating of course, should be equal to the load current, or the current which is flowing through this terminal. So, all the switches must be carrying at least this amount of current. What about the voltage rating of the switches? So, how do I know what is the voltage rating of the switch? I can know the voltage rating of switch for example; for S 1 by turning on the other switches and seeing how much S 1 has to block, how much voltage S 1 has to block.

So, therefore, suppose I turn on S 3, ok. Of course, remember I cannot turn on S 3 and S 2 simultaneously, then I will have a short here. I also cannot turn on S 1 and S 2 simultaneously, then I will short this one. I also cannot turn on S 1 and S 3 simultaneously then it will short this one. So, S 1, S 2, S 3 cannot be turned on simultaneously, only one at a time.

So, therefore, if I now want to know the voltage rating of S 1; then suppose I turn on S 2 ok, I turn on S 2, then this points potential will come here and so S 1 has to block, the full DC bus voltage,. And hence the voltage rating of S 1 should be equal to V d right; voltage rating of S 1 should be equal to V d, this is what is shown on this one

Similarly, if I want to know the voltage rating of S 2 I will turn on S 1, I will turn on this one and we will see how much voltage comes across S 2 that it has to block. So, therefore, once I turn on S 2, this point this plus terminal will come and will be at the same potential here. So, S 2 has to block the full DC bus voltage and hence its rating is V d. What is the rating of S 3, what is the voltage rating of S 3?

Now, when S 1 is turned on, when S 1 is turned on; then the plus terminal of this DC source comes here and so the S 3, the maximum voltage rating of S 3 is V d by 2 with a plus here and a minus here, like this, and this will happen when S 1 is turned on ok, the plus here and minus here. On the other hand if I turn on S 2, then the minus terminal of this DC source comes here and so, S 3 has to be, the voltage rating of S 3 has to be V d by 2 like before.

However the minus point or minus terminal comes here, so it has to block such a voltage, right; so which means that, this S 3 has a voltage rating of half of S 1 and S 2. However, it must block bi-directional voltage; it should have the capability to block bi-directional voltage, as you can as we have just explained. So, this is what is shown here that, S 3 can have or needs to have plus V d by 2 and minus V d by 2 as the bi-directional voltage capability.

So, this kind of a bi-directional voltage blocking capability is for example, possible through this kind of a circuit here; where you see that, you have a transistor and a diode in series, an IGBT and a diode in series like this, ok. So, if you want to, suppose this, this side is plus and this side is minus; so the device will not conduct until you turn on this transistor here, ok. Only when you have turned on this IGBT, the device will conduct, if the current direction is like this.

So, it can block the plus here and the minus here. Of course, the diode on this side will block this one here, right.

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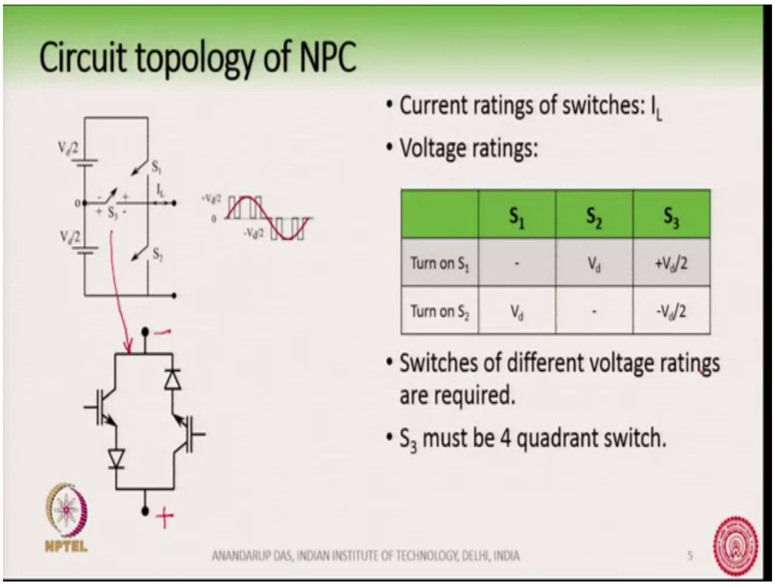

	S_1	S_2	S_3
Turn on S_1	-	V_d	$+V_d/2$
Turn on S_2	V_d	-	$-V_d/2$

Now on the other hand if you have a situation like this, then once you turn on this transistor the current will flow like this; this is a bi-directional voltage, this circuit can block bi-directional voltage. So, we need S 3 as something like this here; S 3 must be made something like this, this kind of a circuit here.

So, what we understand here is that, switches of different voltage ratings will be required in this circuit and S 3 must be a 4 quadrant switch; it has to block both voltages on the both sides plus and minus and it has to carry current in both the direction. Next is like we want to, if I want to use switches of same rating; suppose I want to use switches of same rating, because in the last slide we saw that we need switches of V d for S 1 and S 2 and V d by 2 for S 3, last slide we saw that.

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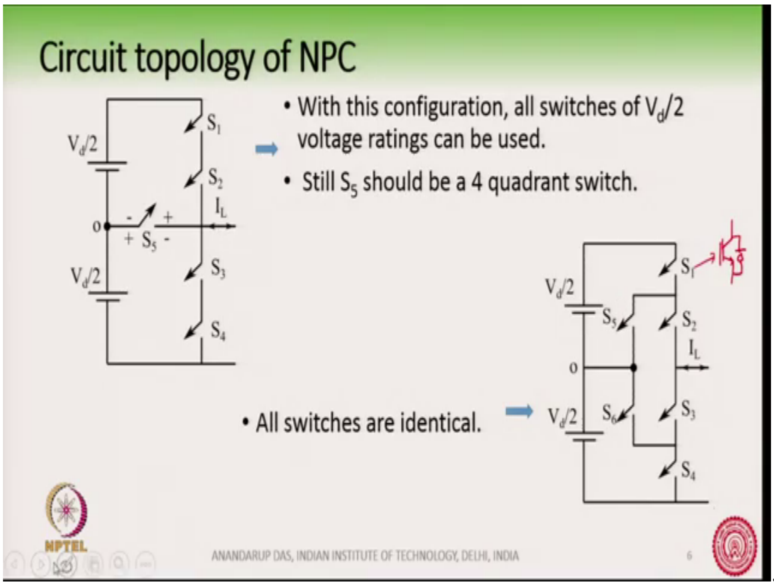

Suppose I want to use all switches of V d by 2 voltage rating, then I can make a circuit arrangement as shown here. So, you have S 1 and S 2 here series connected. So, once you have series connected, the voltage rating of these two switches will reduce to half. So, then S 3 and S 4 also V d by 2 and S 5 is already V d by 2. So, still what will happen is S 5 it is still should be a 4 quadrant switch, ok. Although we have made all switches of the same voltage rating, but still S 5 will be a 4 quadrant switch.

In order to make S 5 this switch similar to these switches; so we can make a circuit like this, where the functionality of this switch can be partly taken care by S 2 and S 5 together here. In this circuit which I have shown here all switches are identical, they have the same voltage and current rating and all of them are identical and there, so each switch is something like this. All the switches in this circuit is something like this, all of them are identical ok; and all of them have a rating of V d by 2 and a current rating of I L.

Now, later it was also realized that, it may be actually possible to have only diodes in place of IGBT plus anti parallel diode in place of S 5 and S 6, it is also possible. So, people had realized that.

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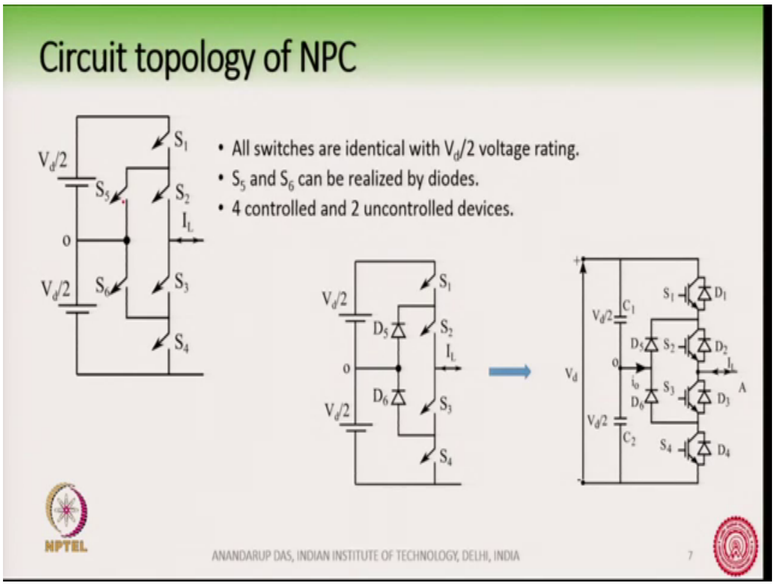

So, then if you explain this a little bit, but S 5 and S 6 may not be IGBT and anti parallel diodes together or a transistor anti parallel diode together, it is not needed. So, we can only have diodes here D 5 and D 6.

So, the overall converter or overall NPC, the Neutral Point Clamp Converter for one phase looks like this; you have two diodes like this and you have four switches. The four switches all have transistor with anti-parallel diodes, ok. These diodes D 5 and D 6 are called clamping diodes; because they are used when the 0 point or the 0 voltage needs to be accessed, we will see this operation just now.

So, what we have done is, we have tried to derive the topology of this three level Neutral Point Clamp Converter, how it came up from the concept of a conventional two level voltage source converter. So, this is the one phase of the converter and so, we have also the three phase of the three level NPC shown here.

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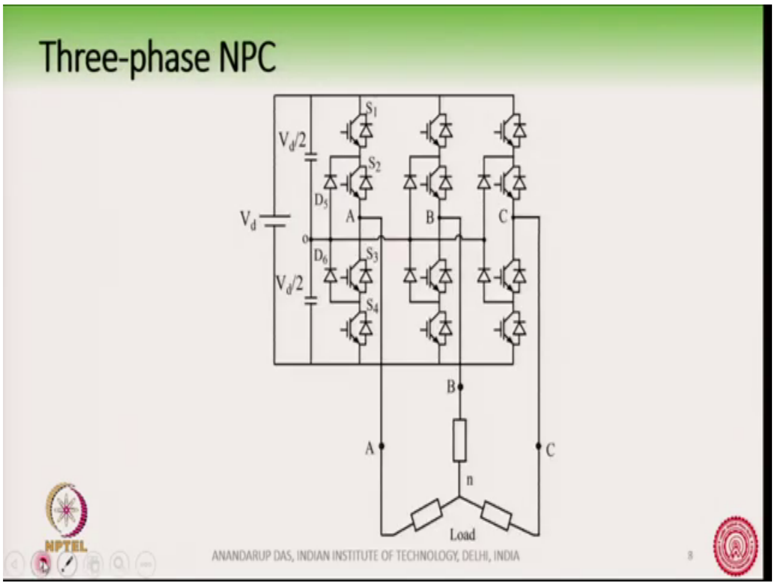

Here you see that, you have this as the one phase, the midpoint of the capacitor is connected to this point here; it is also connected here for the B phase, it is also connected to here at the C phase.

So, the midpoint of the converter or midpoint of the DC bus is physically accessible and it is used in a Neutral Point Clamp Converter. There are four transistors with anti parallel diodes along with two clamping diodes; D 5, D 6. And similarly in the B phase also you have clamping diodes, C phase also you have the clamping diodes, ok. So, we will now see the operation, detailed operation of this converter.